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Sound Data Collection and Transmission Noise Reduction

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SOUND DATA COLLECTION AND TRANSMISSION NOISE REDUCTION

A Thesis Project

Presented in Partial Fulfillment of the Requirements for

The Degree Bachelor of Science and Bachelor of Arts with

Honors College Graduate Distinction at Western Kentucky University

By

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ABSTRACT

The WKU Engineering Department Senior Student Team, The Synchronizers, has been contracted to modify a MTD transmission's sound characteristics. This project entails developing a sound data acquisition apparatus and method, developing a sound test stand which will fully load the transmission and load characteristics, and suggesting modes of sound modification. The Sound Data Acquisition method entails using a specialized microphone calibrated to operate on IOS devices to measure Sound Intensity. The sound intensity will be found over a collective area, in order to evaluate to the sound power generated. The sound test stand will consist of a system designed to drive the transmission, introduce friction and thereby torque, and a system that will measure the rpm of the axle, and the torque experienced by each axle. Potential modes of modifying sound characteristics include modifying current gear design, introducing shims, and introducing sound characteristic material. As the project has developed the end result has been shaped into a sound test bed and sound data acquisition system which shall be useable by MTD as they test alternative methods of sound modification.

Keywords: Mechanical Engineering, Transmission, Sound Intensity, Sound Power,
Sound Data. Gear Noise

ACKNOWLEDGMENTS

I would like to acknowledge all those who helped this project as it has developed over the last year. First and foremost I would like to acknowledge MTD for providing this opportunity. It has been a fantastic opportunity interacting with Brian Hellinger, David Kelly, Lary Ferguson, and Paul Crawford. Without their request and support this project would never have left the ground.

In addition, I would be remiss if I did not acknowledge our Advisor Professor Byrne, and my team members. Professor Byrne has been incredibly helpful through the development, evolution and completion of this project. Without his support this project would have failed midflight.

The Synchronizer team has been incredibly helpful additionally. The Team consists of Abdulrahman Almannaa, Darko Palkic, Dalton Sowers and myself. Darko Palkic has been instrumental in the construction of the test bed. Dalton has provided high quality attention to detail in the development of potential alternate gears for the transmission, and Abdul has been hard at work this entire semester developing and systematizing alternative methods of sound reduction. Without their effort we could not have soared as high as we have.

VITA

January, 27,1991……………………………..Born – Fort Worth, Texas

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PUBLICATIONS

FIELDS OF STUDY

Major Field: Mechanical Engineering

Major Field: Philosophy

Minor Field: Mathematics

Minor Field: Systems Engineering

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INTRODUCTION AND HISTORY

MTD is a company that makes lawnmowers and other lawn care equipment. The plant located in Leitchfield Kentucky specializes in making transmissions for their base model riding lawnmowers. These transmissions have been used for over twenty years with minimal changes. Recently, there has been a growing consumer complaint regarding the noise generated from the transmission during its operation, stating that the sound emitted is unpleasant.

In an effort to resolve this issue, WKU Mechanical Engineering students have been issued a senior project to determine the noise characteristics. Therefore, the purpose of this project is to create a testing apparatus in order to evaluate a given transmission as requested by MTD. The three primary elements of this project are to create the test bed which will take the transmission and simulate the load typically generated by a lawn mower, to create a sound data acquisition apparatus, or S.D.A.A. with a toolkit for relevant analysis, and produce a list of potential sound reduction methods that may reduce either sound generation or transmission. As a member of this team, I will be contributing to this effort by taking a lead role in developing a method of collecting

Figure 1: Ad Featuring MTD Riding Mower that one of the transmissions is found in.[1]

relevant sound data, determining what data is relevant, and deciding how to interpret that relevant information.

Originally, there were two teams developing paths toward a resolution toward this project's end. The original Synchronizers Team consisted of Brad Cockrel, David Shirclif, Dalton Sowers, and Ryan Howell. The second team was "The Gear Factor" which consisted of Abdulrahman Almannnaa, Jon Bal, Darko Palkic, and Nick Thompson. At the end of the fall semester both teams presented their developments and the best elements were chosen moving forward.

Figure 2: The Original Team Logo's

[1] "MTD Lawn and Riding Mower Products." MTD Products.

For the test bed both teams developed a variance on a prony break system with a drill press driving the transmission. The Gear Factor Design, featured on the left below utilizes a system comparable to car brakes where a friction pad is hydraulically pushed into the wheels. In contrast the Synchronizer method, featured on the right below, uses hydraulics to increase the tension in a friction rope about the wheel in order induce friction.

In contrast, the sound systems were quite different. Gear Factor recommended using hardware typically used for music studio's while the original Synchronizers recommended using a type 2 microphone standardized for industry environments and calibrated to work on IOS devices. The audio program chosen by Gear Factor was WavePad Sound Analysis while the original Synchronizer's chose SignalScope Pro, a program designed to work through IOS devices. In addition, different methods of reducing sound generation were explored by both teams, with Gear Factor researching the details of gear crowning and the Original Synchronizers researching spiral bevel gears.

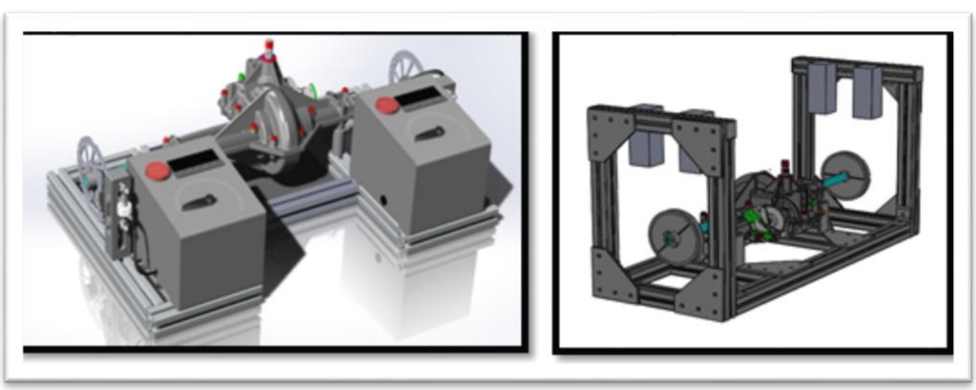

Figure 3: Test Bed Apparatus- Gear Factor(Left) and Old Synchronizer(Right)

The collective cost of the system proposed by Gear factor was $6,225, the breakdown of which may be seen in the appendix. However, it should be noted that this does not include machining cost or the cost of a computer. It may be more accurate to estimate an addition $2000 for machining and an additional $500 for a computer, cumulating in a new total cost of $8,725. In comparison, the collective cost of the Old Synchronizer proposal was $1,593. At the end of the fall semester the team was consolidated to consist of Darko Palkic, Dalton Sowers, Brad Cockrel and Abdulrahman Almannaa, and requisitioned the Synchronizer team name. The new team decided to move forward with the Gear Factor's decision on the pony brake system with drill press, andthe original Synchronizer's Sound Data Acquisition system, while pursuing details on both gear crowning and spiral bevel gears. The collective cost of the new set up was $6,272, which includes the machining and computing cost.

Part Number	Description	Quantity	Cost Each
160-0867	Wilwood 10" Steel Brake Rotor	2	$91.43
120-12178	Wilwood GP 200 Brake Caliper	2	$91.60
95066A152	18-8 Stainless Steel 3/4-8 ACME Hex Nut	2	$15.15
95061A630	18-8 Stainless Steel 3/4-8 ACME Threaded Rod 1-ft	1	$58.95
5908K13	Ultra-Corrosion-Resistant Stainless Steel Ball Bearing	2	$29.26
LCR-500	Rugged S-Beam load cell, 500 pound capacity	2	$290.00
60645K161	Steel Ball Joint Rod End	4	$6.58
94895A825	Zinc Yellow-Chromate Plated Steel Hex Nut (50 PACK)	1	$8.20
90107A033	Type 316 Stainless Steel Flat Washer 1/2" ID (PACK OF 25)	1	$9.71
92620A748	High-Strength Grade 8 Steel Cap Screw 1/2-20	4	$4.90
91022A156	17-4 PH Stainless Steel Socket Head Cap Screw 1/4-20	4	$18.00
94895A029	Zinc Yellow-Chromate Plated Steel Hex Nut 1/4-20 (PACK OF 100)	1	$3.22
92141A029	Type 18-8 Stainless Steel Flat Washer 1/4" ID (PACK OF 100)	1	$3.37
92620A607	High-Strength Grade 8 Steel Cap Screw 5/16-24 (PACK OF 50)	1	$11.74
92141A030	Type 18-8 Stainless Steel Flat Washer 5/16 ID (PACK OF 100)	1	$5.10
94895A810	Zinc Yellow-Chromate Plated Steel Hex Nut 5/16-24 (PACK OF 100)	1	$5.29
MC238	EXEDY OE REPLACEMENT CLUTCH MASTER CYLINDER INTEGRA DEL SOL CIVIC	2	$21.26
260-11098	Wilwood Master Cylinder Remote Reservoir	2	$20.93
DP41-W	Omega Panel Display	2	$625.00
6094K160	Indicating Knob, Round Shaft, Brass Insert, 2-1/2" x 5/8", 5/16" Depth	2	$2.65
610004ERL	EARLS 10 FT. PC HOSE - SIZE 4, ID .1875	1	$36.68
AT983204ERL	Earls Straight -4 AN Bulkhead	2	$6.16
618104ERL	Speed-Seal Hose End Hose Size -4 Nut Size 4 Material Steel Adjustable Tube 180	1	$22.38
600104ERL	Speed-Seal Hose End Hose Size -4 Nut Size 4 Material Steel Straight	1	$7.71
G7948	Grizzly G7948 - 12 Speed 20" Floor Drill Press	1	$808.00
6061K108	Hardened Precision Steel Shaft 10"	1	$5.55
6544K74	General Purpose Low-Carbon Steel 10 Gauge Sheet Metal (24" X 36")	2	$92.72
6527K374	6-FT Low-Carbon Steel Square Tube (1.5" X 1.5")	3	$35.36
player-6th-generation-latest-mod	Ipod Touch	1	$300.00
-Calibrated-Measurement-Extern	Microphone (MicW i436 Calibrated Measurement Type 2 External Mini Microphone)	1	$120.00
aberacoustical.com/apps/ios/sign	Signal Scope Pro (Program)	1	$75.00
N/A	Machining Cost	1	$2,000.00
HHT12	Economical Non-Contact Pocket Optical Tachometer	1	$160.00
		Total	$6,277.22

Figure 4: Current Materials List and Cost.

The Original plan of the two teams was to spend the first half of the semester constructing the Sound Test Stand, and the second half of the spring semester verifying the applicability of the selected sound data acquisition method. However, as the new team approached the spring semester, we realized that we needed to take our time before rushing into accepting the work of the previous teams. As we looked into the test bed that we chose, we reaffirmed out decision in favor of it. However, we found that we needed to make a few changes, such as resizing some holes and choosing an alternative force gauges, and a drill press with variable speed. In addition we wanted to have more in-depth comparison between the Gear Factor sound acquisition method and the original Synchronizer method. After researching gear crowning and spiral bevel gears, we found that the time and expertise required to produce a favorable design was beyond our scope. Therefore we sought the assistance of Paul Crawford and Dave Kelly from MTD who provided us with the insight and connections necessary to move forward. In the end, we decided that our role would be best used to begin the conversation of a new gear change between Gleeson and MTD. As time has progressed the problems have been solved and appropriately addressed. However, this time has provided an offset to our original timetable in the construction of the test bed. Therefore, the team deviated from the original goal by verifying design for the first half the semester, taking an additional fourth of the semester to construct the test bed, and using the last quarter of the semester to verify the validity of the chosen sound data acquisition method.

CHAPTER 2

TEST BED

Initially, resolving the noise issue appeared straight forward; however, as the project progressed several necessary tasks arose. The first of was the design of test bed. The first challenge associated with the test bed was developing a way to power and mount the transmission such that its forces experienced would accurately represent the forces experienced when mounted within an actual lawnmower. This transmission is powered through the use of a single input shaft, indicating only one power source would be necessary to run the transmission properly. As far as loading the transmission is considered, the axles extending from the transmission experience a load on the end as a result of the mowers weight resting on the attached wheels. Therefore, powering the transmission through the input shaft at operational conditions and submitting the transmission to loads at the end of each axle becomes necessary for accurate testing.

The proposed method of introducing resistance into the system is to develop a “prony brake” system that would simulate the operational conditions the transmission would typically experience in a riding lawn mower. This prony brake consists of a brake pad being hydraulically pushed into a transmission plate in order to increase resistance, thereby creating an torque load.

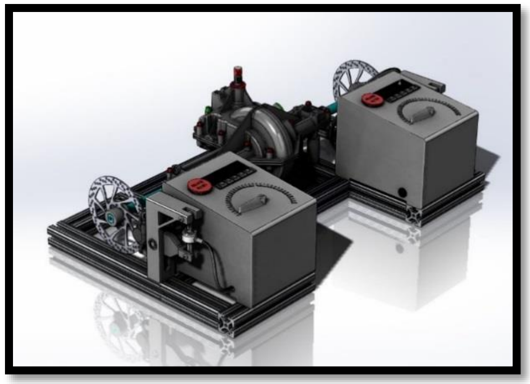

Figure 5: 3D model of chosen test stand.

In addition, the team will be using a tachometer to measure the rpm of the metal disks meant to simulate the wheels. As the transmission is powered, the rotational movement disks will be slowed as friction is introduced via the brake pad. Through the use of this system, the total output torque of the transmission can be quantified through the use of a simple equation relating the radius of the wheel to the force being enacted on the force gauges by the transmission.

As for the physical test frame holding the transmission, 40:40 aluminum extrusion will be utilized due to its ease of use, along with its structural capabilities. The frame is

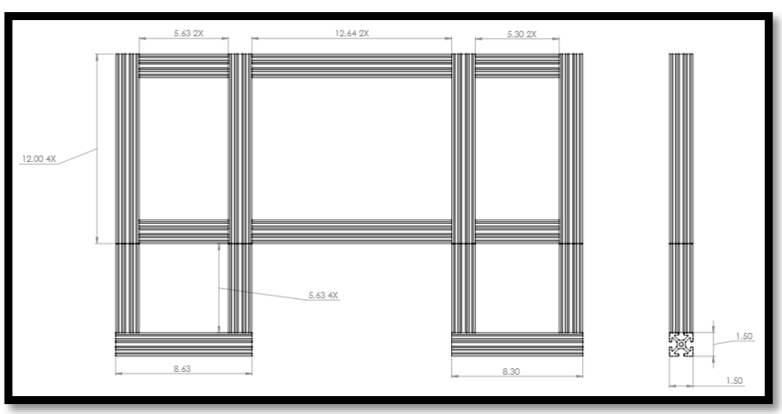

Figure 6: Physical Test Frame

built around the dimensions of the transmission so as to provide adequate clearance during the mounting process. Mounting the transmission consists of placing four bolts through the transmission's dedicated holes with a vibrational dampening washer resting between the casing and the frame.

We sent the frame to be machined by ProSteel. After the team received the test stand the team made a few adjustments before final assembly. The test bed was completed mid-April, and is illustrated in figure 7.

However, as experimentation continues it may become more necessary to introduce varying dampening sources into the test bed. The team will have to consider all possible noise sources outside of the transmission, as well as those generated, by the transmission. External sources include the drill press and the test bed itself. The key to reducing the noise generated by the drill press will be to add mass to the enclosure around the pulley system within the drill press. The vibrations traveling throughout the transmission and test bed may be reduced through the use of spring and rubber dampeners and isolators.

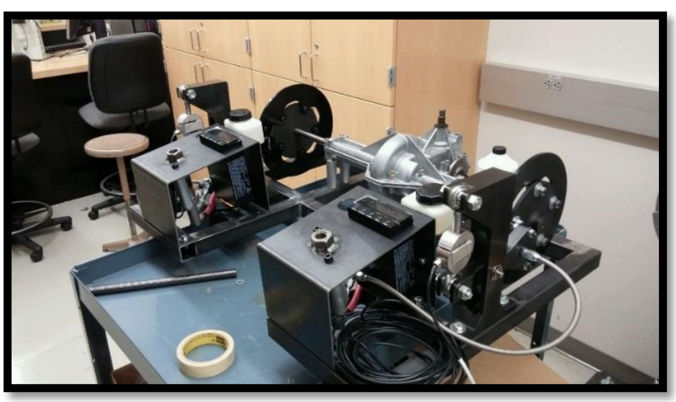

Figure 7: Completed Test Stand

CHAPTER 3

SOUND DATA ACQUISTION THEORY

Now that the transmission was successfully mounted and powered, the amount of noise that was produced by the transmission will be quantified. The team turned its attention toward addressing how to quantify the sound characteristics of a frequency and intensity of the sound will be measured, resulting in the development of a sound and a procedure to collect the data.

The first step to addressing the issue is to define sound. Sound is produced by the oscillatory motion of fluid, fluid pertains to both gas and liquids.[2] Sound physically happens through longitudinal and transverse waves. Sound is related to longitudinal waves insofar as that longitudinal waves are the form through which sound waves traverse fluids.[3]

Sound is related to transverse waves insofar as that transverse waves are also a primary mode through which sound travels through solids. For example, when someone hears a fog horn in the distance, they are hearing sound through traverse waves. In contrast, when someone puts their ear to the ground and hears the rumbling of a distant

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[2] Crocker, Pg.1.

[3] Herrin. "Lecture 1"

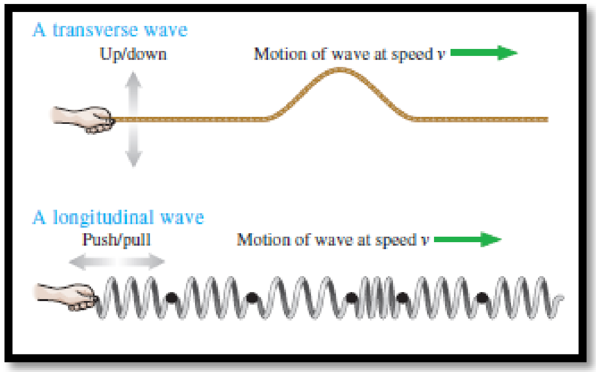

Figure 8: Knights illustration on transverse and longitudinal waves[4]

herd of horses galloping, they are experiencing sound through transverse waves. Within this project the primary mode of sound generation will be longitudinal. However, it is worth noting that the vibration generated from the rotational force in the transmission will travel throughout the entire transmission and tested apparatus. Therefore, transverse waves will be a part of the system. However, these waves must travel through the air to reach the human ear and will therefore be ignored insofar as data collection is concerned. Traverse waves may be a source of excessive noise within the lawn mower mechanism itself. However, it is the goal of this project to evaluate the transmission individually. Therefore, the team will do its best to isolate and dampen excessive transverse wave effects.

Sound may be defined scientifically in several different terms. One often thinks of decibels, but this is an overly simplistic view. A decibel simply refers to a logarithmic unit which is generated by a ratio of two values. When someone refers to decibel they could be referring to sound power level, sound pressure level, or sound intensity level.

[4] Knights, pg. 561

The original units of sound power level are watts, the original units of sound pressure are pascals, and the original units of sound intensity are watts per meter squared. Sound power level refers to the logarithmic ratio between actual power and the reference power of $10^{-12}\ Watts$. In comparison, sound pressure level refers to the logarithmic relationship between actual sound pressure and the reference sound pressure 20 micro pascals, which "corresponds to the quietest sound that the average young person can here".[5] Finally, sound intensity level refers to logarithmic ratio between the actual intensity over the reference intensity of 1 pico watt per meter squared.

It is worth noting that sound pressure and sound intensity are often related and confused for the same thing. However, sound pressure is a "sound field quantity" and sound intensity is a "sound energy quantity" The equations for sound pressure level, sound power level, and sound intensity level are found below in figure 9.

6.1 Sound Pressure Level

The sound pressure level L_p is given by

$$L_p = 10\log_{10}\left(\frac{\langle p^2\rangle_t}{p_{\mathrm{ref}}^2}\right) = 10\log_{10}\left(\frac{p_{\mathrm{rms}}^2}{p_{\mathrm{ref}}^2}\right) = 20\log_{10}\left(\frac{p_{\mathrm{rms}}}{p_{\mathrm{ref}}}\right)\ \mathrm{dB} \quad (32)$$

6.2 Sound Power Level

The sound power level of a source, L_W, is given by

$$L_W = 10\log_{10}\left(\frac{W}{W_{\mathrm{ref}}}\right)\ \mathrm{dB} \quad (33)$$

6.3 Sound Intensity Level

The sound intensity level L_I is given by

$$L_I = 10\log_{10}\left(\frac{I}{I_{\mathrm{ref}}}\right)\ \mathrm{dB} \quad (34)$$

Figure 9: SPL, SWL, and SIL Equations[6]

[5] Crocker Pg. 11

[6] Crocker, Pg. 11.

The Original goal of this project was to me to reduce the decibels generated by the transmission by 20%. However, as the various types of decibels are illustrated it becomes apparent that these instructions beg the question, what sort of decibel should be reduced, should the sound pressure or sound intensity be reduced where the rider is located, or should the sound power level be reduced at the transmission? There are two potential responses to this question. First, that the problem is coming from the transmission and therefore should be stopped and measured at the source. Alternatively, one might argue that the rider is the person who is experiencing the sound and the measurements ought to be taken from that perspective.

One important way of looking at the question is exploring what is actually experienced. Sound power is the actual energy transmitted by the sound source. However, the sound pressure level is what is actually realized through experiencing the sensation known as hearing. A sound source generates sound power. This sound power radiates in plane waves which may be estimated as sound intensity, or sound power per planar area resulting in units of $\frac{watts}{meter^2}$. The difference between sound intensity and sound pressure is velocity, where multiplying a pressure by velocity would create $\frac{watts}{meter^2}$. However, "Sound intensity measurements do and should give the same result as sound pressure measurements made in a free field"[7]. However, it is important to note that this project will not entail a free field due to the braking systems which will impact the sound as measured on either side of the test bed. Additionally, the drill press will impact the

[7] Crocker Pg. 26

results from behind as well as the top of the test bed. Therefore, free field measurements will be impractical for the current test bed.

In conjunction, it is important to note that background noises should be minimized in order to ensure accurate results. When exploring these two measurements, sound pressure and sound intensity, an important consideration is simplicity. Sound pressure is the simplest method of measuring sound because it only requires one microphone, where measuring sound intensity requires two microphones calibrated to work in conjunction and find sound intensity.

In an attempt to mitigate risk, expand versatility, and invest in simplicity I decided, with the team's approval, to pursue sound pressure level measurement. This method is advantageous because the sound pressure is proportional to the sound intensity, and the sound power may be calculated by measuring the Sound Pressure Level over a plane, at a specific distance. This is illustrated from a point source illustrated below.

This method of measuring sound power will not be applicable in this case. However, given proper modification one may reduce the ways in which the free field resistances. Assuming such modifications were made, one may modify surface area seen, in figure 10, as a sphere will be simulated as a cube instead. It is worth noting that the equations sound pressure in this equation is not sound pressure level, but sound pressure itself. If the measurement tools estimate sound pressure level one will use the equation 32 in figure 9 to retroactively find the sound pressure in order to calculate the sound power level using the equation seen in figure 10.

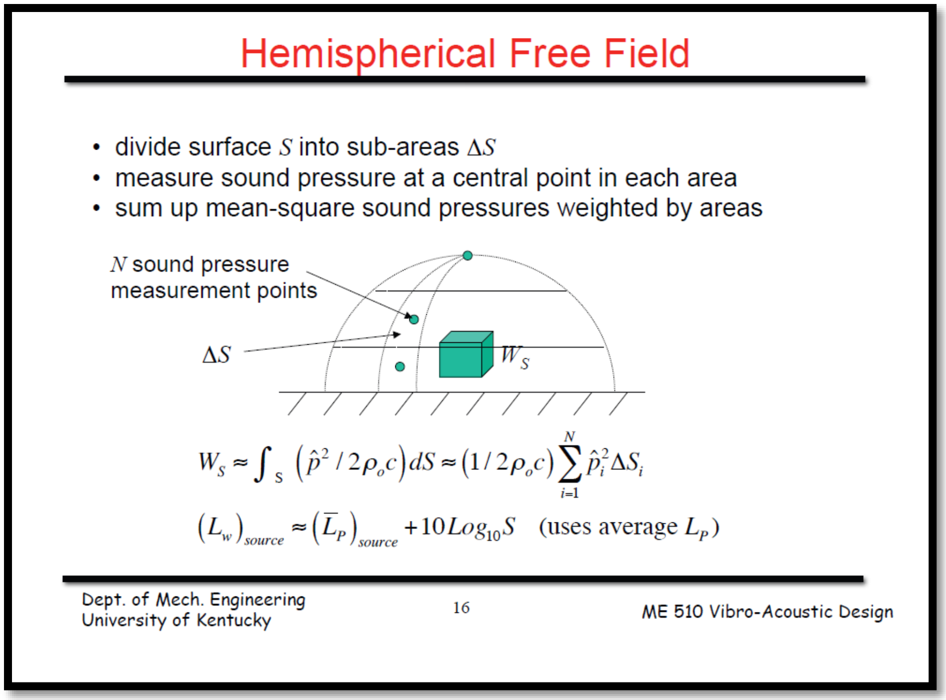

Figure 10: Sound Pressure Level and Sound Power Level relationship[8]

Using this method one can convert the found sound pressure level into sound power. The only question of accuracy is how well the free field is maintained and how well background noises are reduced.

A question moving forward might be "what sort of sound pressure levels are expected from a transmission." Figure 11, is a graphic that illustrates the typical sound pressure levels generated by various noise sources. A Power mower should generate somewhere around 100 dB. Therefore, it will be important to analyze the frequencies about that decibel level.

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[8] Herrin. "Lecture 5 slide 16."

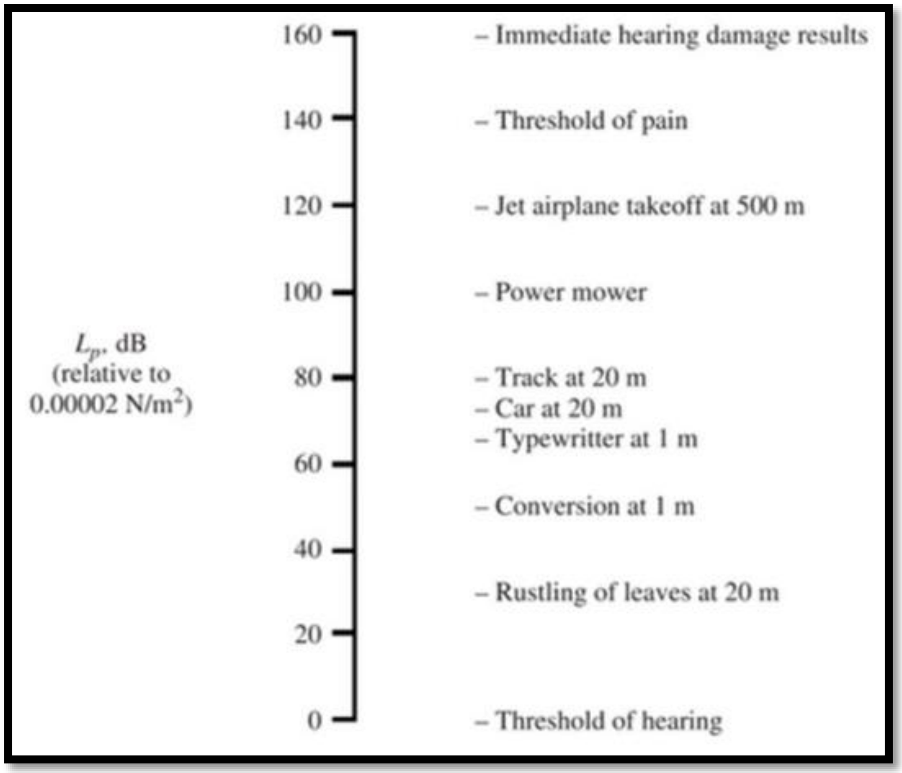

Figure 11: Some typical sound pressure levels L_p[9]

Standards about these noise sound pressure levels have been standardized by OSHA in relationship to frequency. “Protection against the effects of noise exposure shall be provided when the sound levels exceed those shown in Table G-16 when measured on the A scale of a standard sound level meter at slow response.” Table G-16 is found at the top of the next page in figure 12

[9] Crocker. Pg. 11

TABLE G-16 - PERMISSIBLE NOISE EXPOSURES (1)

Duration per day, hours	Sound level dBA slow response
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
1/2	110
1/4 or less	115

Footnote(1) When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. If the sum of the following fractions: C(1)/T(1) + C(2)/T(2) C(n)/T(n) exceeds unity, then, the mixed exposure should be considered to exceed the limit value. Cn indicates the total time of exposure at a specified noise level, and Tn indicates the total time of exposure permitted at that level. Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.

Figure 12: Permissible Noise Exposures[10]

This table, in figure 12, shows that the sound level is A-weighted. This A weighted dB level may be measured by taking a octave band sound pressure level (dB) and plotting this on the graph at the top of the next page. This graph illustrates the relationship between octave band sound pressure level and the equivalent A-Weighted Sound Level and its relationship to frequency. One may note that there is not a linear relationship between A-weighted dB and sound pressure level, at given frequencies the difference between the sound pressure level and A-weighted sound level varies such that at 2000 Hz is 90 dB and approximately 92 dB where the difference at 8000 Hz is 115 dB and 120 dBA.

[10] United States Department of Labor. "Occupational Safety & Health Administration."

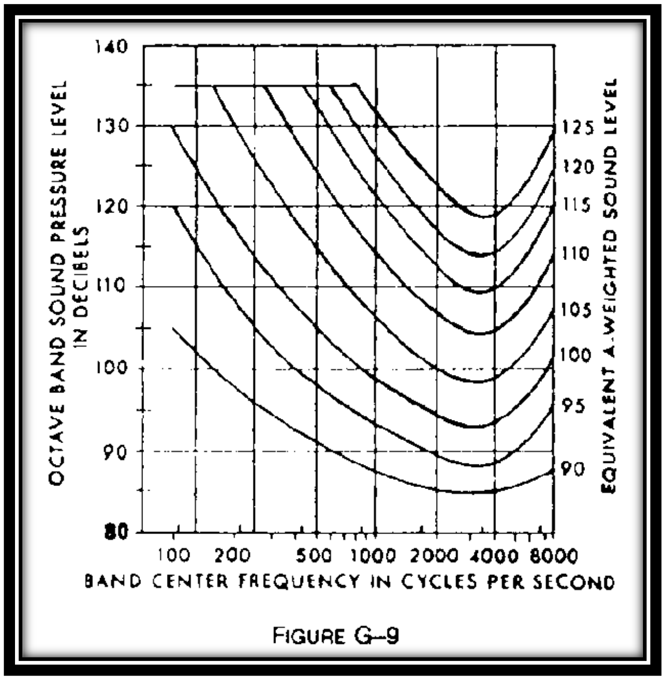

Figure 13: Relationship between SPL and A-Weighted Sound Level[11]

This numerical difference is illustrated in more detail at the top of the page in figure 13. Here the parabolic nature is shown where the least difference appears least strong around 4000 Hz.

It is also worth defining A-weighting. Human beings hear frequencies at different levels. In effect, human beings have difficulty hearing sounds at lower frequencies such that that they sound significantly softer. A frequency at roughly 100Hz will sound 20dB quitter than it actually is, compared to its actual sound pressure level. In effect at sound with a pressure level of 40 at 100 Hz would roughly sound like it has a sound pressure level of 20 to human beings. This relationship is illustrated in figure 14.

[11] United States Department of Labor. "Occupational Safety & Health Administration."

Relative Response (dB)	Frequency *f* in Hz									
	31.5	63	125	250	500	1000	2000	4000	8000	16000
dB(A)	−39.4	−26.2	−16.1	−8.6	−3.2	0	+1.2	+1.0	−1.1	−6.6
dB(C)	−3.0	−0.8	−0.2	0	0	0	−0.2	−0.8	−3.0	−8.5

Figure 14: Numerical relationship between SPL and A-Weighted Sound Level

Additionally, this relationship is illustrated more fully below in figure 15. This illustration is more complete because it shows the full relationship, as opposed to just the select points available in figure 14.

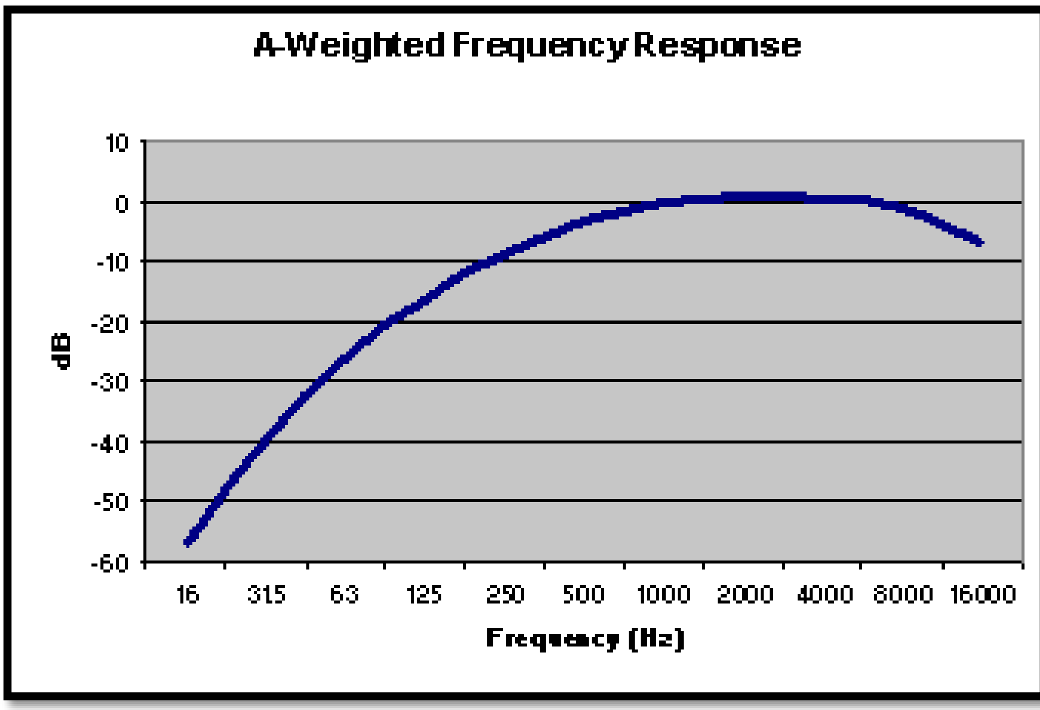

Figure 15: Human Ear Frequency Response[12]

[12] Noise Meter Inc. "Frequency Weighting."

In summary, sound has been defined in terms of sound power, sound pressure, and sound intensity. The relationship between the terms and their logarithmic level values has been defined in order to illustrate the nature of decibels. Sound pressure level has been defined as the mode through which human beings hear sounds. Typical sound pressure levels from various sources have been provided in figure 11. OSHA requirements for sound in the workplace have also been defined. Through the illustration of sound science a basic understanding of sound and how it might impact this project has been provided.

CHAPTER 4

SOUND DATA ACQUISITION METHODS

The original teams developed two modes of collecting sound data. The first method, developed by the team gear factor, revolves around using music studio software and hardware to measure frequency and sound pressure accurately. In comparison, the original synchronizer team's method revolves around utilizing an IOS synchronized systems to measure sound pressure level and frequency. Each method has a significantly different set of hardware and software.

The Gear factor methods entails using a Shure 137 microphone. This microphone has a fairly accurate frequency response between 300Hz and 20,000 HZ. The sensitivity of the microphone is calibrated at -37 $\frac{dB*V}{Pa} * (14.1mV)$. These details are illustrated in the specification sheet attached in the appendix in figure A1. This microphone requires a pre- amplifier, specs as a Behringer Tube Ultragain MIC 100. The program used is WavePad FFT Sound Analyzer. This software will be able to compare frequency and sound pressure level. However, it will require calibration between the microphone amplifier system and the computer driving the program.

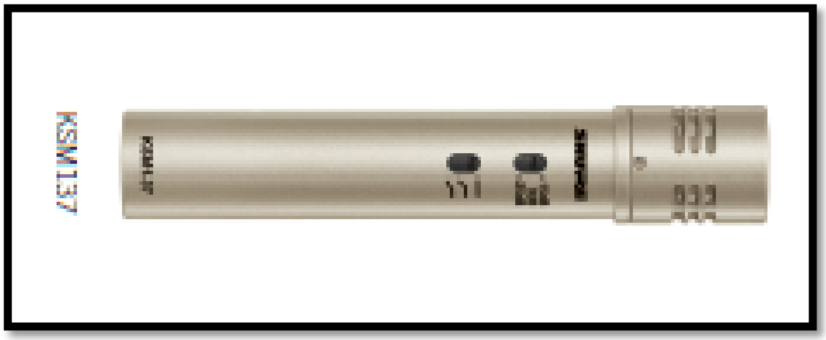

Figure 16: Shure 137 Microphone[13]

The original synchronizer team method entails using a MicW i436 microphone. This microphone has a very accurate frequency between 0Hz and 20,000Hz. The sensitivity of the microphone is calibrated at $-44(\mathrm{dB}) * \left(\frac{6.3\mathrm{mV}}{\mathrm{Pa}}\right)$. The details are illustrated in the specification sheet in figure A2. This microphone is synchronized to work with IOS products. The program specified is SignalScope Pro. This program is an App which can be bought through the apple store. The IOS device chosen was an I pod touch. One of the beneficial elements of this method is that everything is synchronized. The microphone is calibrated to work with IOS devices and the IOS devices.

[13] "Product Specifications - KSM137." *Shure*.

Figure 17: MicW i436[14]

The original synchronizers method was more advantageous insofar as all of the hardware and software are specifically designed to work with each other. Alternatively, the gear factor method would require calibration between the preamplifier's signal level and the microphone's signal level.[15] Both microphones are Electret Condenser microphones. The MicW microphone also has a larger range of accurate frequency. An additional advantage in favor of the MicW microphone is that the polar pattern is more round and therefore measurements will be easier to take. Along this line of reasoning, the synchronizer sound data acquisition method will be simpler, easier, and versatile as it will not be dependent on any heavy equipment. One can easily carry the microphone and I-touch in one's hand. In contrast the Gear Factor method requires the use of pre-amplifier's and computers at hand.

[14] "MicW i436 Specification." *Mic-W*.
[15] Lewis, Analog Dialogue.

Figure 18: Sound Data Acquisition Apparatus (S.D.A.A)

In summary, the MicW microphone is more accurate over a greater range of frequencies, especially on the lower frequency end. This is wider range is important insofar as that before experimentation, the current frequencies generated by the transmission are an unknown due to the unique sound characteristics of the transmission. The MicW 436 microphone, I touch and Signal Scope Pro program is a more simple set up in regards to calibration. This simplicity adds value in so far as it means that this sound data acquisition apparatus is more easily replaced. This microphone is also more versatile. The versatility of the apparatus is particularly relevant in regards to testing noise generated by a transmission within a lawnmower. This method allows for easy access to field testing. If one wanted to use the Gear factor method on an active lawn mower while it was active mowing, this would require finding a power source outside, moving the computer and amplifier outside, and either trying to mount those on the lawn mower or having a extensive length of wire for one's hardware. Therefore, because the MicW i436 microphone is more accurate over a greater range, more versatile, and simpler in setup I decided that this method would be the most advantageous for MTD's Transmission Testing.

In order to verify a noise reduction of 20%, we have ascertained a method of measuring Sound Power. In order to find the Sound Power, the team will utilize a microphone calibrated to interface with IOS devices, a IOS device, and an empty cube frame around the transmission. The apparatus will collect sound Intensity information, about the empty planes of the cube frame. By multiplying the plane area by the mean sound intensity, sound power will be provided. Additional frequency spectrum analysis, will also be made available via this method.

This is the desired method of measuring the noise generated when one wants high quality measurements. However, one may also estimate the noise by using the sound pressure level alone. The sound intensity level and sound pressure level are what is actually experienced; in contrast the sound power level is what is actually generated. This is illustrated below in figure 19.

If one is purely concerned about what the rider of the lawn mower is hearing one may measure the sound pressure level of the lawn mower as they drive it. This will allow for an estimate in regards to the actual sound generated. However, it is only the density of

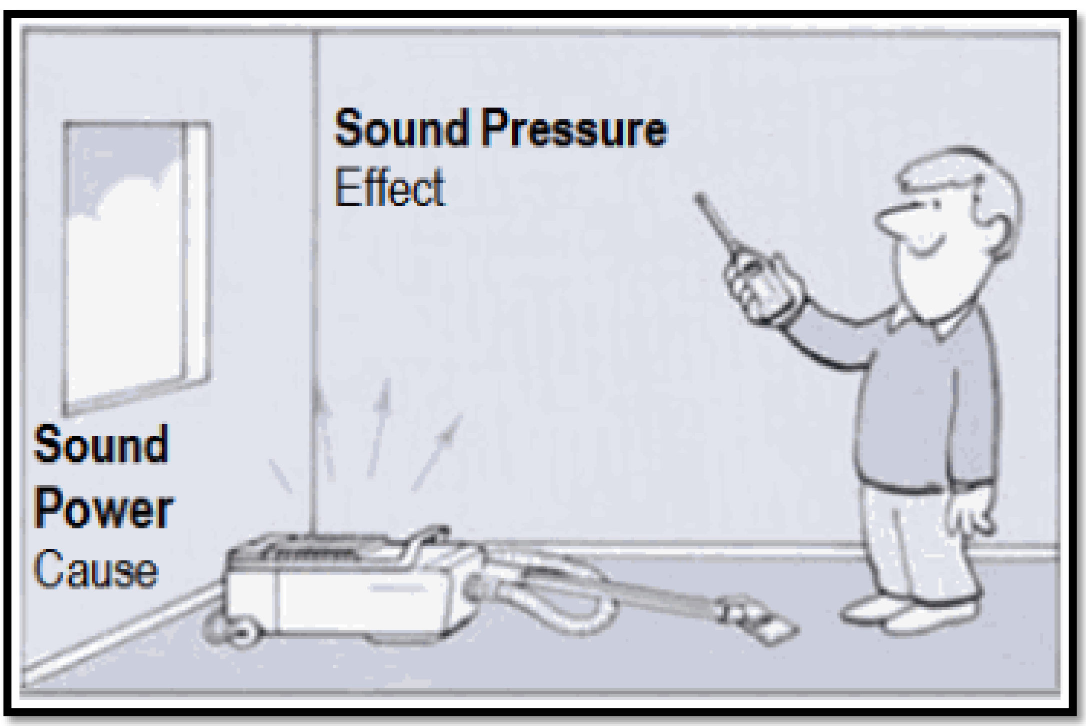

Figure 19: Sound Power and Sound Pressure Relationship

power experienced at that point in space, that point being where the microphone is, which is being measured. This does not address to the actual power that is being generated. However, it does provide a convenient and effective tool for use estimating and investigating noise generated by the transmission.

As this project has progressed it has become apparent that this test bed will not adequately simulate a free field environment where the sound power level generated by the transmission may be accurately measured. Therefore, strictly measuring the sound pressure levels and frequency and comparing these measurements at a given moment in time to charts which graph human hearing discomfort will be the best available indicator on where the transmission sound currently stands will sufficiently quantify the sound data desired. An example of sound data as experienced by a human is illustrated below in figure 20. One may note that at frequencies between two and five kHz, the lowest decibel level is required to reach the pain threshold.

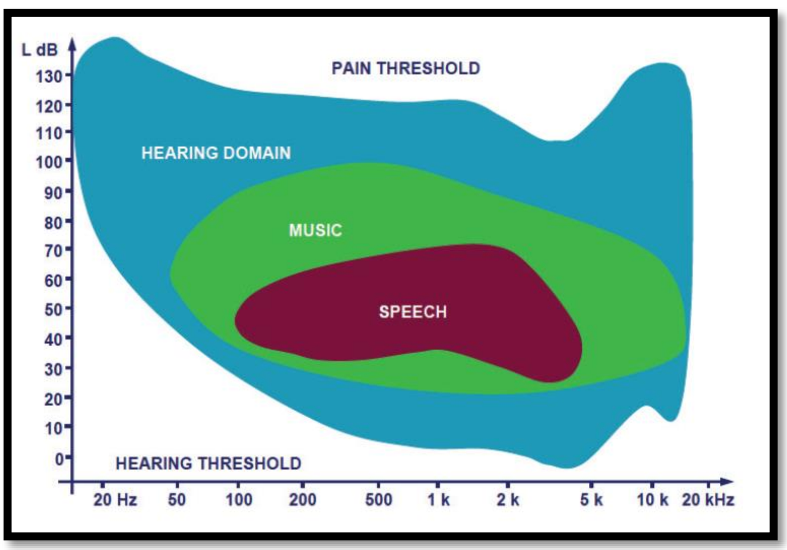

Figure 20: ME 510 Vibro-Acoustic Design lecture 1

CHAPTER 5

SOUND DATA ACQUISITION APPARATUS GUIDE

The following is meant to be a guide on how to set up the sound data acquisition apparatus, how to operate this apparatus, and the best methods of collecting sound data.

To set up the sound data acquisition apparatus one must first set up the I-Pod Touch. When one opens up the brand new I touch, the first step is to set up the icloud account. After one has an ICloud account the next step is to log into that account on the app store. When at the app store search for Signal Scope Pro. Buy this app. After the app is bought one must simply plug in the Mic i436 microphone and the sound data acquisition apparatus is complete.

When operating the device the first step is to turn it on and activate the Signal Scope Pro app. The app will have multiple options. These options include the fast fourier transform analyzer, the octave analyzer, the oscilloscope, the level meter, and the signal generator. The FFT shows sound pressure level vs frequency, displayed on a logarithmic scale. The octave screen shows Sound pressure level vs Frequency. The Oscilloscope screen shows amplitude vs time. The sound level meter shows the sound pressure level at a given response level.

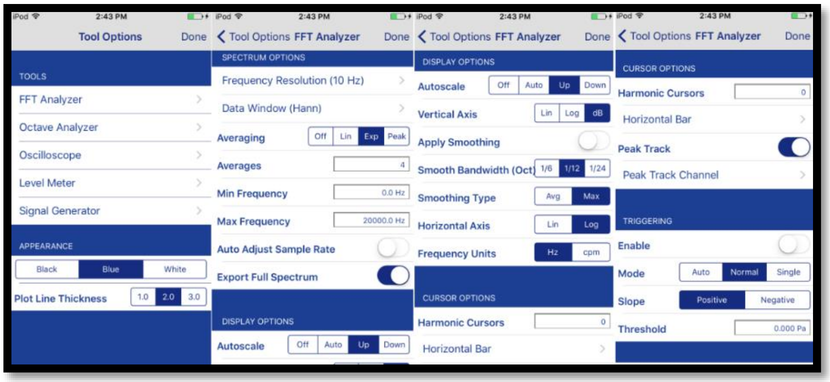

Figure 21: FFT Set up

In order to correctly set up the FFT analyzer tap the image that looks like a graph on the top of the screen. This will take you to the tool Options. From here tap FFT analyzer. Verify that the Frequency resolution is 10 Hz, that the Data Window is Han, that the averaging is Exp, that the averages is 4, that the min Frequency is 0 Hz, that the max frequency is 20kHz, that the Export Full Spectrum is active, that the Auto scale has selected Up, that the Vertical Axis is in dB, that smoothing is not applied, that the smooth bandwidth octave is (1/12), that the smoothing type is max, that the horizontal axis is Log, and that the Frequency Units are in Hz. With these settings the FFT analyzer data ought to be easily decipherable via the I Touch itself.

In order to set up the Octave Analyzer tap the image that looks like a graph on the top of the screen. This will take you to the tool Options. From here tap Octave Analyzer. Verify that that the Bandwidth is (1/3) Octave, that the Level Type is L_p, that the Freq Weighting is Flat, that the Time Weighting is Fast, that Auto Stop is Off, that the Auto scale is Up, that the Secondary Level is off, that Draw Div Lines is on, and that the Frequency is in Hz.

Figure 22: Octave Analyzer Set up

In order to set up the Oscilloscope Analyzer tap the image that looks like a graph on the top of the screen. This will take you to the tool Options. From here tap Oscilloscope. Verify that the Auto scale is up, and that the time scale is (5 $\frac{\text{ms}}{\text{Div}}$). The Level Meter will require no set up.

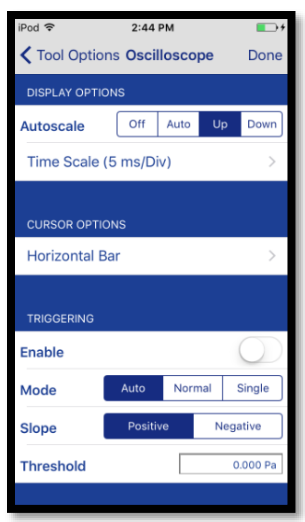

Figure 23: Oscilloscope

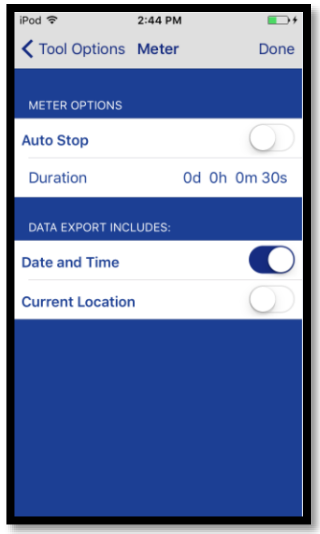

Figure 24: Level Meter Set up

Now that the Analyzers have been set up the question becomes what is the best mode of collecting data in order to accurately evaluate the sound generated the transmission. The mode of sound collection will be sound pressure level vs frequency. One may use these measurements to find sound power, or simply use the sound pressure level measurements.

For an in-depth test, one that uses sound pressure level and sound power level, the first step is to set up the test bed apparatus. After the test bed is set up, construct a cube frame around the test bed. Activate the test bed, and apply adequate load to simulate the lawnmower and create the sound of interest. Take the Sound Data Acquisition Apparatus, plug in the microphone, turn on the I Touch, activate the app, tap FFT, and then tap the play button at the top of the screen. The device will then begin collecting data. Trace the microphone at an even pace throughout the empty space of one of the side of the cube. When complete click the pause button. Tap export data, then tap the square with an arrow pointing up at the top of the screen, this will bring up an export prompt. Tap export data, name the file, and save the file. Repeat this operation on all available side of the cube. When all available side of the cube have been measured take the Sound Data Acquisition Apparatus to the computer that the I-touch is synched with. At this computer export the data. From here find the mean sound pressure level of each measured face of the cube frame. Using the Mean Sound Pressure level, and the area of the cube frame face one may then find the Sound Power Level generated by the transmission.

One may also estimate the noise generated by the transmission at a specific point by simply using the sound pressure level that is given at a given point in time. However, this is does not actually estimate the noise generated but rather the noise experienced. This sort of testing will be quite relevant when testing a transmission in an actual lawnmower because of all the material that sits between the rider and the transmission, as well as other sources of noise within the lawn mower. This method will also be very useful in the current transmission test bed apparatus because it will not require free field measurements like the sound power level measurements would require. However, this method will not be as useful in holistically measuring the sound generated. This method is about taking single snapshots in time in a single location, where the sound power level measurement allows for a more detailed understanding of the waves being emitted from the transmission. For the purposes of this project a simple sound pressure level vs frequency measurement is sufficient to measure the current sounds experienced from the transmission, and comparing that data with the results of the teams attempts to make that sound softer.

Once the data has been collected the next step is to take it from the iPod and analyze it. To collect the data plug the iPod into a computer that it is synched with. When connected go to iTunes, from there go to your iPod apps. Click signal scope Pro. From here, one should see the data collected on the bottom right hand side of the screen. Copy this information and store it in a memorable location. One should have a csv file, a txt file, and a excel file. One may recreate the excel file using the text file by copying the information and pasting it in the top right of a blank excel sheet. Save the excel sheet as a new file. Delete the supplementary information so that only the data remains. The left hand data will be frequency and the right hand data will be decibel.

This information can then be copied into a provided excel sheet which will plot that information onto a graph which is super imposed over a figure which illustrates the hearing thresholds of a human. An example may be seen below in figure 25. The closer that the data is to the pain threshold the more unpleasant the sound. This excel spreadsheet can be created by the following the instructions in figure 26.

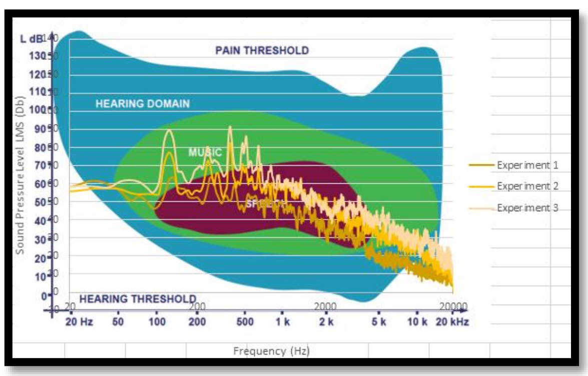

Figure 25: Sample Experimental Results when plotted.

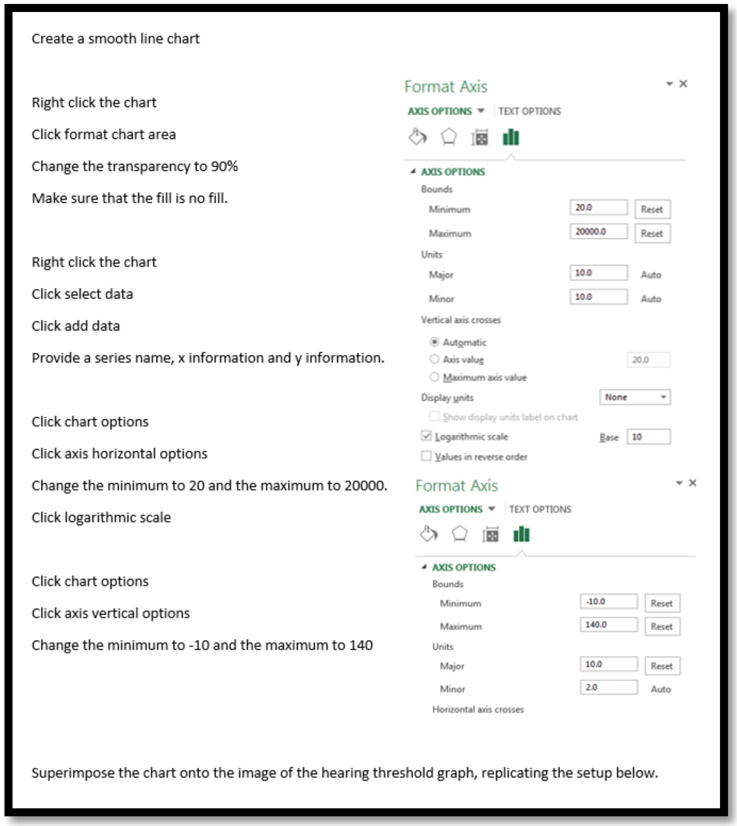

Figure 26: Instructions on creating a experimentation

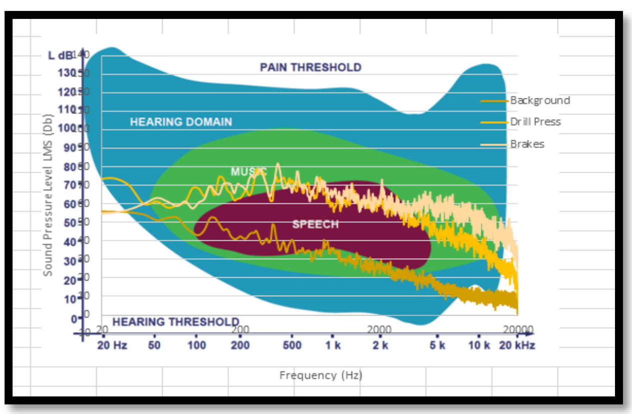

Figure 27: Background Noises

Through the team's experimentation, background data was able to be found and is illustrated in figure 27. This allows for a more clear analysis of the drill press data, which is illustrated below in figure 28

One may note that the background noise is fairly high in frequency, where the transmission noise is fairly low in frequency. However, this experimentation is also pre-noise generation. Essentially, this is the sound of a healthy transmission, not the problematic sound the team is meant to root out.

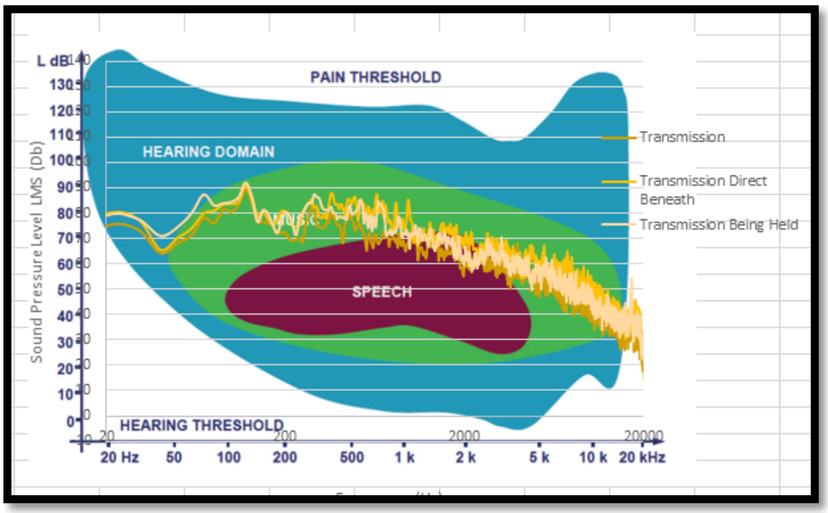

Figure 28: Transmission Noise

CHAPTER 6

TRANSMISSION SOLUTIONS

With research the team has developed methods of powering the transmission, measuring the torque, and collecting the sound data. The next step was to actually change the noise characteristics generated by the transmission. Both Gear Factor and the Original Synchronizer Team developed several methods of potentially reducing the noise generated.

The original synchronizer spent the most time developing ideas about Helical Gear Mesh concepts, adding bearings or bushings, and maintaining a tighter tolerance on current gears. Helical Gear Mesh Concept Helical meshes are quieter than spur meshes primarily due to their higher face contact ratios. Gear meshes generate acoustic disturbances or noise due to the structural vibration response of the gear caused by the sudden release of strain energy as each loaded gear tooth rotates out of mesh contact. A helical gear tooth mesh has more teeth sharing the load across the pitch line at any given instant than an equivalent spur gear mesh. One of the main problems with helical gears is a whine that occurs when they are spun in reverse. This issue should not be as prevalent in low speed applications though. Helical gears also have the potential to be more expensive to make, however helical gears are also stronger than regular straight cut gears. The benefits are that these gears are possibly more efficient, possibly cheaper to make due to size, but would require fluid and that the transmissions be made oil tight. An additional method of impacting the noise characteristics was adding bearings or bushings. These would be made to be press fit inside the gear to maintain a tighter tolerance around the shaft. Instead of the current bushings being utilized within the transmission, a thrust bearing could be used. A thrust bearing would provide for the transmission to run smoother possibly producing less noise while allowing for the same, if not better, functionality. Replacing bushings with bearings would increase the price of the transmission, varying according to the quality of the bearing. This method would entail potentially eliminating need to use anti-weld paste, potentially improve efficiency of transmission, and an added cost of something less than 5 dollars for a bearing or bushing.

The third most researched idea from the Old Synchronizer team was to maintain a tighter tolerance on current gears: The bevel gears currently being used have been known to be produced inconsistently, specifically concentricity and perpendicularity to the shaft. Tightening up the tolerances on these gears would possibly increase the performance and the overall quality of the transmission while reducing the noise produced from bad gear meshing. Since the inside diameter of these gears is machined it should be fairly easy to hold the inside diameter to a tighter tolerance that fits the shaft better.

In addition to these ideas additional solutions such as sound damping, alternate differential fluid, oil tighten differential case, and stiffer housing were all additional methods of positively influencing the noise that is generated from the transmission.

Complimentarily, the Gear Factor Team also developed several methods of reducing the negative noise generated by the transmission. The first concept is gear crowning. This is the most attractive concept because after the initial investment of the production machinery, this concept will not increase the cost of the gears much at all if any. This concept involves shaving the areas of the gear teeth that make contact with the other gear into a curved surface. This will greatly reduce the noise due to misalignment of the gears.

The next concept is using spring washers in place of regular flat washers that are already in place. Spring washers have shown to absorb sound in a mechanical device by deflecting when a force is applied. There are many different kinds of spring washers with different spring constants so a wide range of washers would likely need to be tested, but these washers are sold at a fairly low cost and would be quick to test.

The final concept is to put a material around the outside of the transmission to absorb the sound. There are many different products that do this already so testing would be fairly inexpensive. This could be a very inexpensive concept if testing shows that only part of the transmission needs this treatment.

These ideas from both teams constitute a list of suggests that our team entails to attach to test bed in hopes that these thoughts provide the creative stimulation required to actively pursue methods of sound alteration. It is expected that this project will result in a sound test bed, a sound data collection apparatus, and a list of potential modes of overall sound reduction generated by the MTD transmission. It is our goal that this outcome will provide for significant impact such that this MTD transmission will remain relevant and competitive within the current lawn mower transmission market.

CHAPTER 7

SUMMARY

In summary, the new Synchronizer team was tasked with developing a Transmission Testing Apparatus, which entails a transmission test bed, a Sound Data Acquisition Apparatus, as well as a list of potential methods of influencing the noise generated. The team has developed a test stand which will be able to accurately simulate the forces a transmission experiences from a MTD mower. This test bed will essentially simulate a car break system driven by a drill press. The concept of sound has been researched so that the value of the measured sound data can be quantified, such that by measuring the sound pressure level in conjunction with frequency, the quality of the sound generated may be quantified. Different methods of sound data acquisition have been compared and the more versatile option was chosen. The original Synchronizer method which I developed allows for use in the field and in more proper testing conditions, while remaining more accurate over a greater frequency range. A guide has been created for the utilization of the Sound Data Acquisition Apparatus. Finally, a list of solutions has been developed so that MTD has several potential methods of impacting the data that they can find through our Transmission Testing Apparatus. MTD has been provided a Test Stand which can simulate the forces of riding lawn mower, an S.D.A.A which can accurately measure and interpret sound data, and solutions for MTD to pursue.

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APPENDIX

Part Number	Description	Quantity	Cost Each
160-0867	Wilwood 10" Steel Brake Rotor	2	$91.43
120-12178	Wilwood GP 200 Brake Caliper	2	$91.60
95066A152	18-8 Stainless Steel 3/4-8 ACME Hex Nut	2	$15.15
95061A630	18-8 Stainless Steel 3/4-8 ACME Threaded Rod 1-ft	1	$58.95
5908K13	Ultra-Corrosion-Resistant Stainless Steel Ball Bearing	2	$29.26
LCR-500	Rugged S-Beam load cell, 500 pound capacity	2	$290.00
60645K161	Steel Ball Joint Rod End	4	$6.58
94895A825	Zinc Yellow-Chromate Plated Steel Hex Nut (50 PACK)	1	$8.20
90107A033	Type 316 Stainless Steel Flat Washer 1/2" ID (PACK OF 25)	1	$9.71
92620A748	High-Strength Grade 8 Steel Cap Screw 1/2-20	4	$4.90
91022A156	17-4 PH Stainless Steel Socket Head Cap Screw 1/4-20	4	$18.00
94895A029	Zinc Yellow-Chromate Plated Steel Hex Nut 1/4-20 (PACK OF 100)	1	$3.22
92141A029	Type 18-8 Stainless Steel Flat Washer 1/4" ID (PACK OF 100)	1	$3.37
92620A607	High-Strength Grade 8 Steel Cap Screw 5/16-24 (PACK OF 50)	1	$11.74
92141A030	Type 18-8 Stainless Steel Flat Washer 5/16 ID (PACK OF 100)	1	$5.10
94895A810	Zinc Yellow-Chromate Plated Steel Hex Nut 5/16-24 (PACK OF 100)	1	$5.29
MC238	EXEDY OE REPLACEMENT CLUTCH MASTER CYLINDER INTEGRA DEL SOL CIVIC	2	$21.26
260-11098	Wilwood Master Cylinder Remote Reservoir	2	$20.93
DP41-W	Omega Panel Display	2	$625.00
6094K160	Indicating Knob, Round Shaft, Brass Insert, 2-1/2" x 5/8", 5/16" Depth	2	$2.65
610004ERL	EARLS 10 FT. PC HOSE - SIZE 4, ID .1875	1	$36.68
AT983204ERL	Earls Straight -4 AN Bulkhead	2	$6.16
618104ERL	Speed-Seal Hose End Hose Size -4 Nut Size 4 Material Steel Adjustable Tube 180	1	$22.38
600104ERL	Speed-Seal Hose End Hose Size -4 Nut Size 4 Material Steel Straight	1	$7.71
G7948	Grizzly G7948 - 12 Speed 20" Floor Drill Press	1	$808.00
6061K108	Hardened Precision Steel Shaft 10"	1	$5.55
6544K74	General Purpose Low-Carbon Steel 10 Gauge Sheet Metal (24" X 36")	2	$92.72
6527K374	6-FT Low-Carbon Steel Square Tube (1.5" X 1.5")	3	$35.36
player-6th-generation-latest-mod	Ipod Touch	1	$300.00
-Calibrated-Measurement-Extern	Microphone (MicW i436 Calibrated Measurement Type 2 External Mini Microphone)	1	$120.00
aberacoustical.com/apps/ios/sign	Signal Scope Pro (Program)	1	$75.00
N/A	Machining Cost	1	$2,000.00
HHT12	Economical Non-Contact Pocket Optical Tachometer	1	$160.00
		Total	$6,277.22

Figure 4: Current Materials List and Cost.

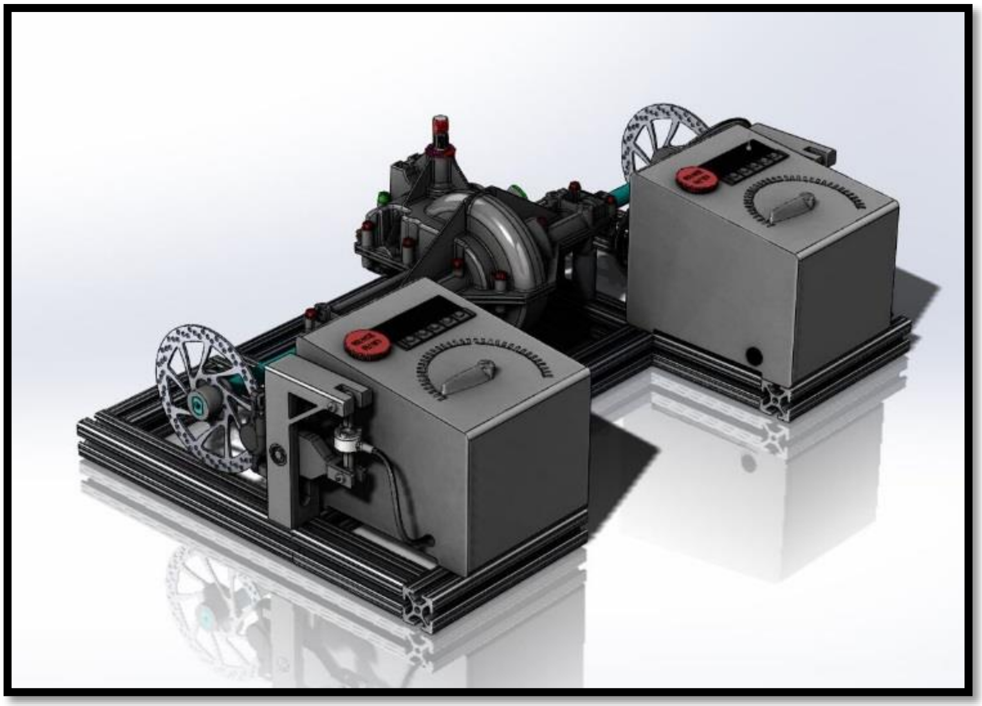


Figure 5: 3D model of chosen test stand.

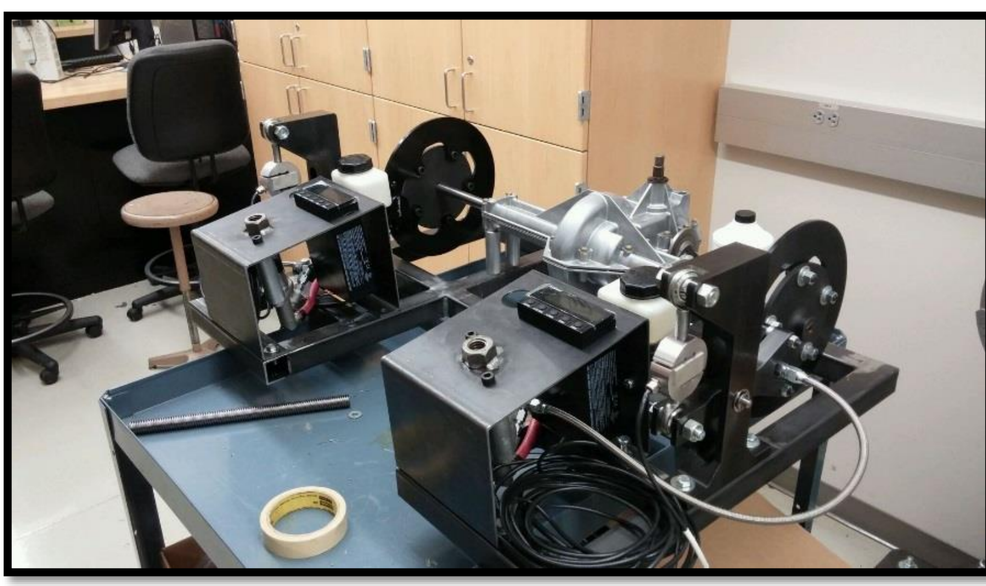


Figure 7: Completed Test Stand

TABLE G-16 - PERMISSIBLE NOISE EXPOSURES (1)

Duration per day, hours	Sound level dBA slow response
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
1/2	110
1/4 or less	115

Footnote(1) When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. If the sum of the following fractions: C(1)/T(1) + C(2)/T(2) C(n)/T(n) exceeds unity, then, the mixed exposure should be considered to exceed the limit value. Cn indicates the total time of exposure at a specified noise level, and Tn indicates the total time of exposure permitted at that level. Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.

Figure 12: Permissible Noise Exposures

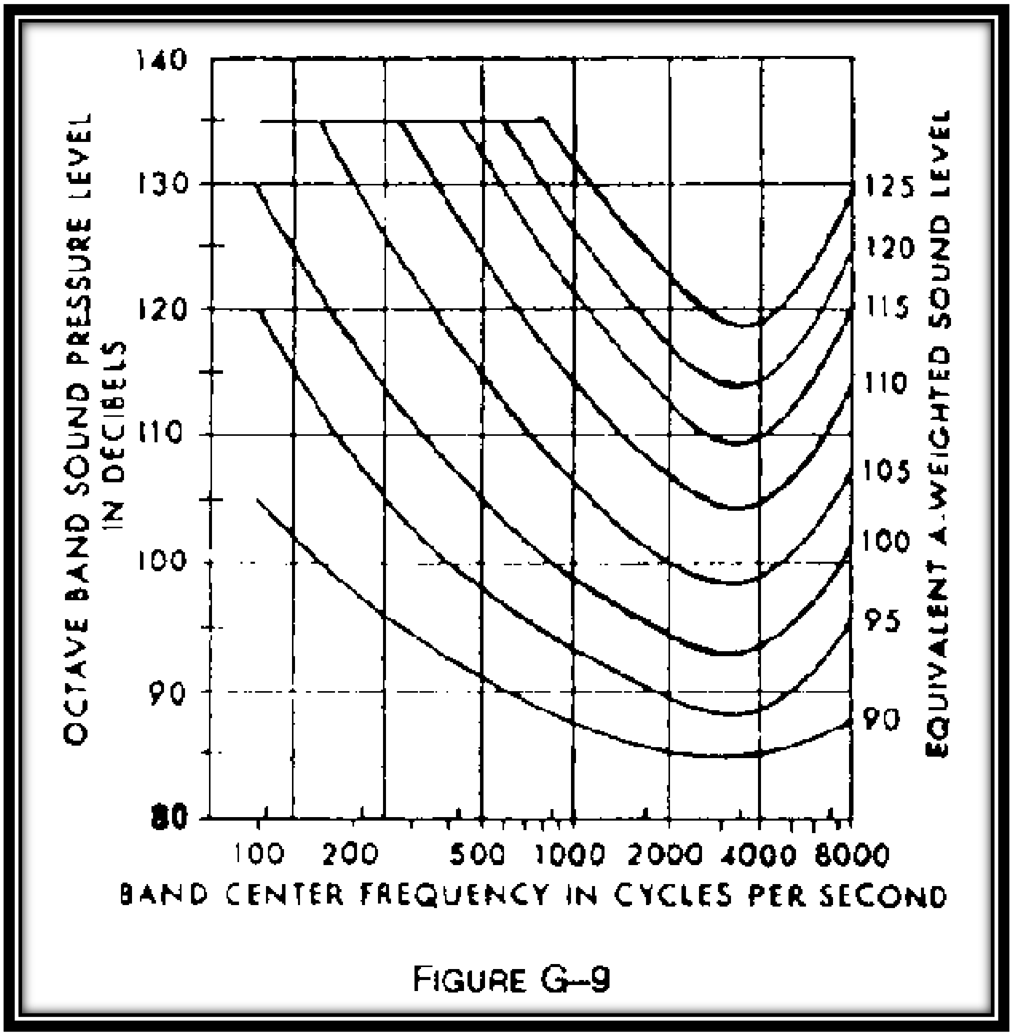


Figure 13: Relationship between SPL and A-Weighted Sound Level

Relative Response (dB)	Frequency *f* in Hz									
	31.5	63	125	250	500	1000	2000	4000	8000	16000
dB(A)	−39.4	−26.2	−16.1	−8.6	−3.2	0	+1.2	+1.0	−1.1	−6.6
dB(C)	−3.0	−0.8	−0.2	0	0	0	−0.2	−0.8	−3.0	−8.5

Figure 14: Numerical relationship between SPL and A-Weighted Sound Level

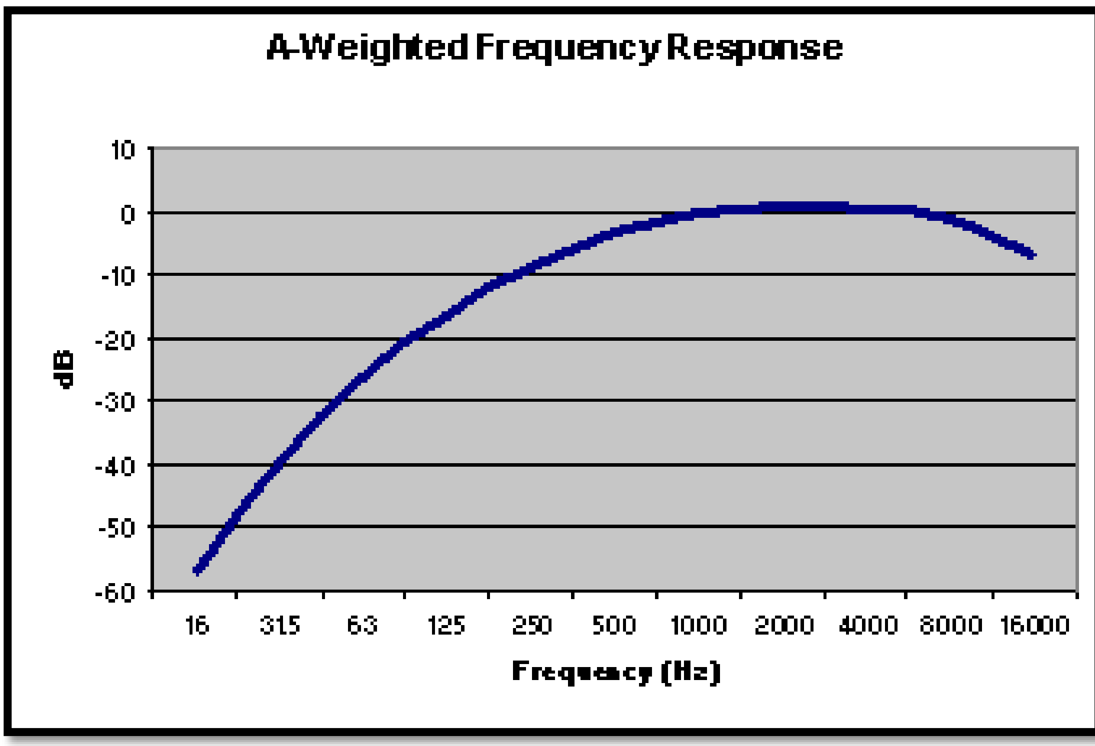


Figure 15: Human Ear Frequency Response[16]

[16] Noise Meter Inc. "Frequency Weighting."

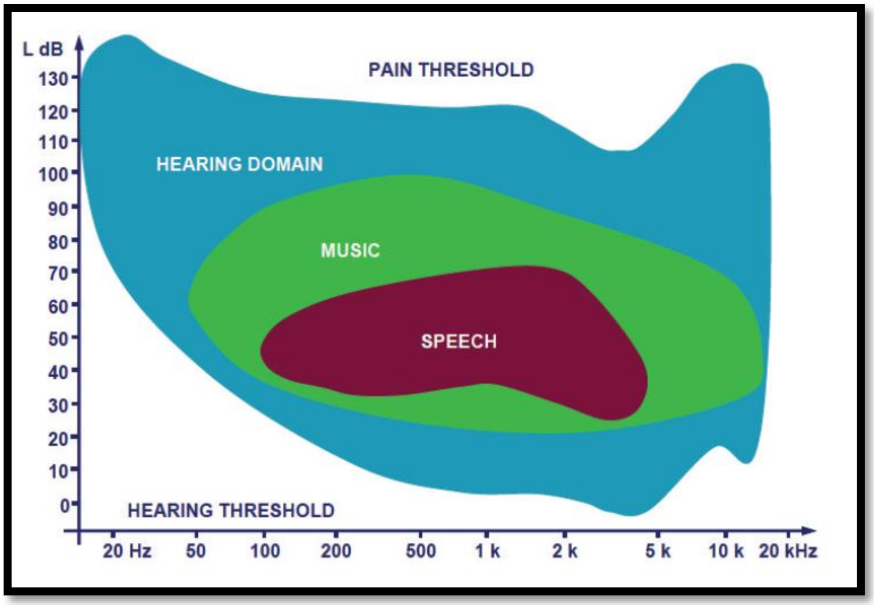


Figure 20: ME 510 Vibro-Acoustic Design lecture 1

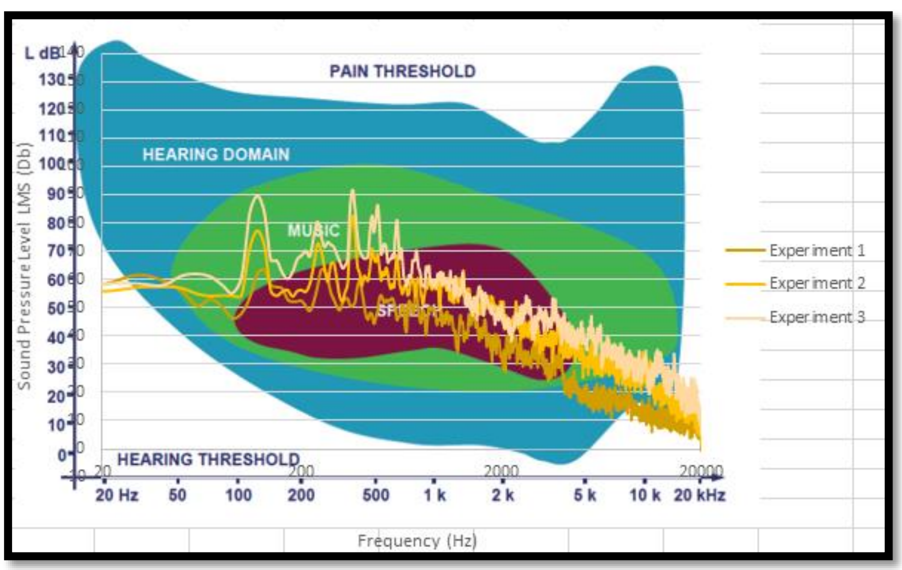


Figure 25: Sample Experimental Results when plotted.

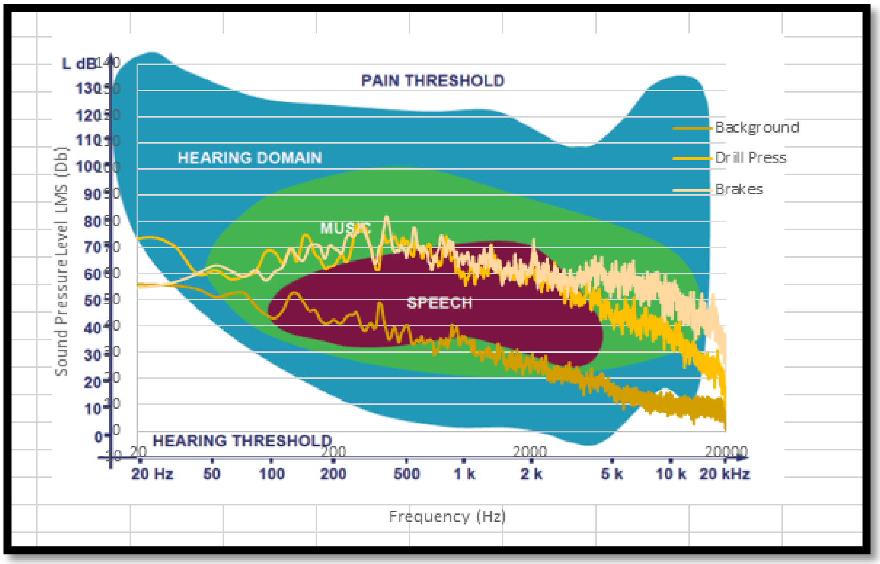


Figure 27: Background Noises

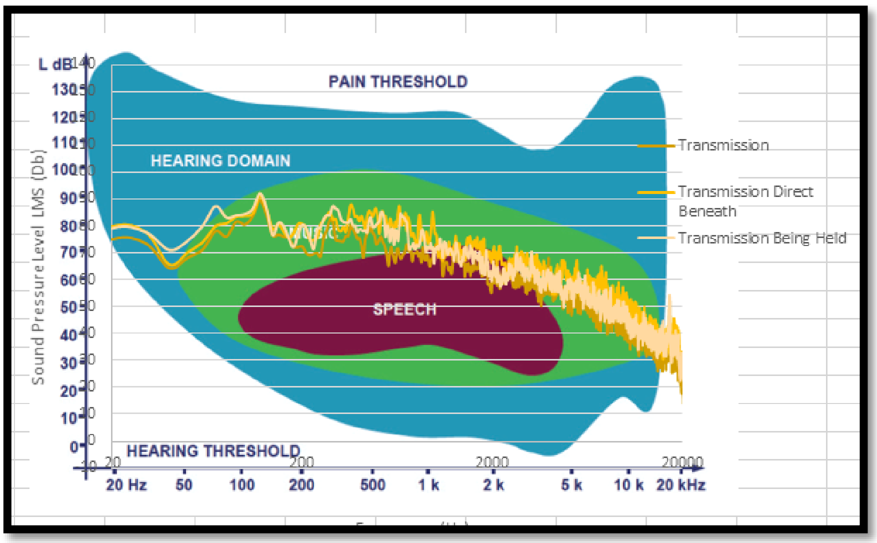


Figure 28: Transmission Noise

Product Specifications

KSM137 End-Address Cardioid Condenser Microphone

Overview

The KSM137 is a premium end-address cardioid condenser microphone engineered for highly critical studio recording and live sound productions. Its class A, discrete, transformerless preamplifier provides extremely natural response and transparent sound capture, and a three position switchable pad allows for handling of extremely high sound pressure levels. Versatile, durable, and precise, the KSM137 is an outstanding microphone for both live and studio applications.

KSM137

Features

- A highly consistent cardioid polar pattern.
- Ultra-thin, 2.5 µm 24 karat gold-layered, low mass Mylar® diaphragm for superior transient response.
- Class A, discrete, transformerless preamplifier for transparency, extremely fast transient response, no crossover distortion, and minimal harmonic and intermodulation distortion.
- Premium electronic components, including gold-plated internal and external connectors.
- Subsonic filter eliminates low frequency rumble (less than 17 Hz) caused by mechanical vibration.
- Three-position switchable pad (0 dB, 15 dB, and 25 dB) for handling extremely high sound pressure levels (SPLs).
- Three-position switchable low-frequency filter reduces background noise and counteracts proximity effect.

Available Models

KSM137/SL	Includes Stand Adapter, Windscreen and Carrying Case
KSM137/SL STEREO	Includes two KSM137, two Stand Adapters, two Windscreens, A27M Stereo Microphone Adapter and Carrying Case

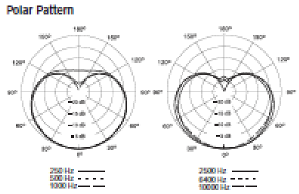
Specifications

Cartridge Type	Electret Condenser	
Polar Pattern	Cardioid	
Frequency Response	20 to 20,000 Hz	
Sensitivity *Open circuit voltage, @ 1 kHz, typical*	-37 dBV/Pa (14.1 mV) *1 Pa = 94 dB SPL*	
Maximum SPL *(1 kHz @ 1% THD)*	No Pad 145 dB 139 dB 134 dB	-25 dB Pad 170 dB 164 dB 159 dB
Signal-to-noise ratio *A-weighted*	80 dB	
Dynamic Range *(@ 1 kHz)*	5000 ohms load: 131 dB 2500 ohms load: 125 dB 1000 ohms load: 120 dB	
Clipping Level *(20 Hz - 20 kHz, 1% THD)*	5000 ohms load: 15 dBV 2500 ohms load: 9dBV 1000 ohms load: 3dBV	
Self Noise *equivalent SPL, A-weighted, typical*	14 dB	
Common Mode Rejection *(10 to 100,000 Hz)*	≥50 dB	
Switch	Attenuator: 0, –15, –25 dB Low Frequency Filter: flat; -6 dB/octave below 115 Hz; -18 dB/octave below 80 Hz	
Connector	Three-pin Professional Audio (XLR), male, balanced	
Polarity	Positive pressure on diaphragm produces positive voltage on pin 2 with respect to pin 3	
Power Requirements	11-52 VDC phantom power (IEC-61938) 4.7 mA, maximum	
Net Weight	100 g (3.5 oz.)	

Furnished Accessories

A100C	Case	**A100WS**	Windscreen
A27M	Stereo Microphone Adapter	**A57F**	Stand Adapter

Polar Pattern



Frequency Response

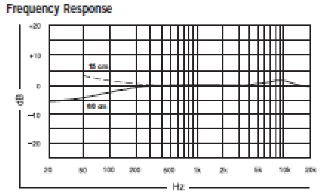


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Figure A1: KSM Microphone Specifications[17]

[17] "Product Specifications - KSM137." *Shure*. Web. 29 Apr. 2016. <http://cdn.shure.com/specification_sheet/upload/32/ksm137-specification-sheet-english.pdf>.

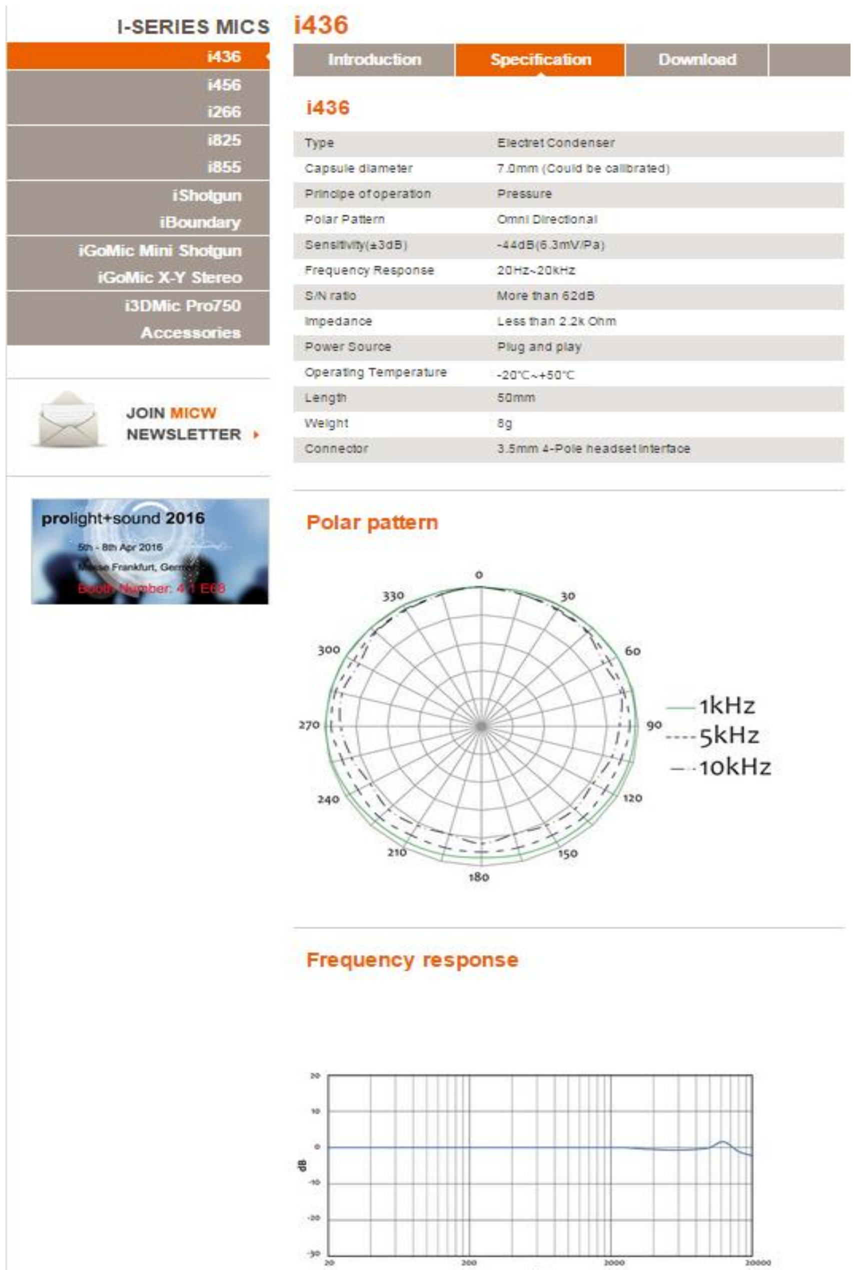

Figure A2: MicW i436 Microphone Specification[18]

[18] "MicW i436 Specification." *Mic-W*. Web. 29 Apr. 2016. <http://www.mic-w.com/product.php?id=3>.